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PARTS SUPPLIERS AS INNOVATORS IN
WIRE TERMINATION EQUIPMENT

Pieter VanderWerf

WP 1289-82

March, 1982

MASSACHUSETTS
INSTITUTE OF TECHNOLOGY
50 MEMORIAL DRIVE
CAMBRIDGE, MASSACHUSETTS 02139



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ABSTRACT

Past empirical studies of the functional sources of process innovations have concentrated on innovations by process users and process equipment manufacturers. This paper identifies an industry in which, according to existing theories of innovation source, firms supplying parts to the production process have an especially high probability of being major innovators. It then presents a sample of economically important process equipment innovations from the industry, and finds that, indeed, such "suppliers" were the source of a majority. There follows a test of the theory that guided selection of the industry -- the theory of economic benefit -- as a predictor of the sources of the individual innovations in the sample. Qualitatively the paper also considers some of the factors that industry interviewees claimed were important additional influences on whether suppliers introduce a particular innovation.

1 INTRODUCTION

Past research has shown that the "functional" source of industrial process innovations can differ significantly from industry to industry. Studies of some industries have revealed users to be the source of most innovations (von Hippel 1976; von Hippel 1977). In other industries most came from manufacturers (Berger 1975; Boyden 1976). It has been hypothesized that these variations can be explained with economic factors (von Hippel 1979), and that under certain conditions "suppliers" rather than users or manufacturers might be the greatest source of innovations in an industry. In particular, suppliers of variable physical inputs to a production process are expected to introduce innovations in the process when their potential profit ("benefit") from doing so is high relative to that of other parties. I.e., if suppliers can get much more profit from originating an innovation than can users or manufacturers, they are the likeliest to do it. Since potential profits from innovation to the different parties vary in roughly predictable ways (according to market structures, market sizes, and profit margins) it should be possible to locate an industry of especially high supplier benefit for further study.

This paper reports on an empirical study to document and investigate the phenomenon of supplier innovation. The researcher chose an industry that seemed a priori to have the conditions theoretically conducive to innovation by suppliers: the industry of electronic wire and cable termination. From this industry a sample was taken of important

equipment innovations, which were then traced back to their sources. Finally the researcher evaluated some possible explanations for the patterns found. The paper begins with definitional and research background. It then outlines the study methods, presents the findings, and considers the relative benefit hypothesis and some other promising explanatory variables.

2 SUPPLIER INNOVATION DEFINED

Following von Hippel (1979, p. 1), the functional source of a process innovation is here defined according to the functional relationship through which the innovator benefits from his innovation. If the innovator implements the innovation into his own production activities to improve them it is a "user" innovation. An example might be new welding equipment invented and developed by an automobile manufacturer for incorporation into his own auto body assembly line. If instead the innovator sells equipment that embodies the innovation it is termed an "equipment manufacturer" or "manufacturer" innovation. This would be the case if improved welding equipment were invented by an industrial machinery manufacturer who then sold it to users for implementation in their plants. And if the innovator benefits because the innovation promotes the use of some other production process input that he sells, it is a "supplier" innovation. For example, it would be a supplier innovation if an acetylene producer invented welding equipment for use by firms

that buy his fuel for their welding work.

In the prototypical supplier innovation, the innovator is a firm that sells some part, component, or material for incorporation by customers into their final products. The supplier invents improved equipment for handling and/or applying its brand of supply item. This makes its brand more attractive to potential users, and some of them switch to it from alternatives sold by other suppliers. The result for the innovator is an increase in sales. In actuality, in every case recorded by this study of a supplier firm inventing application equipment for its parts, the firm also manufactured and sold or leased the equipment (like a manufacturer). These were still unambiguous cases of supplier innovation, however, when the firm made no profit on the equipment directly, but only from its promotional effect on the sale of the companion parts. In a few cases the supplier-innovator also used the equipment in-house (like a user). But again, if the proceeds from internal use were very small relative to the effect on part sales it is reasonable to classify the innovation "supplier."

An illustrative example of supplier innovation is the development of the pneumatic ribbon cable press by the Minnesota Mining and Manufacturing Company. In the late 1960s 3M introduced a new type of electronic cable called "flat ribbon cable." Instead of holding a bunch of discrete wires together in plastic tubing, like most existing multiple-wire cables, a ribbon cable consisted, in effect, of wires laid side by side and fused along their insulations. They thus formed a long, flat "ribbon" of wires. A major potential advantage of the cable was

convenience of "terminating" (attaching) connectors to the ends. (A connector is a sort of "electric plug" on the end of a multiple-wire cable for attaching the cable to a piece of electronic equipment.) Previously a separate contact had to be applied to each wire, and these were then inserted into a connector housing, one contact at a time. But 3M designed a connector that users could terminate over the end of a ribbon cable in one operation: "u"-shaped contacts in the connector pierce the insulation and make contact with the wires inside. Yet despite the ability to terminate ribbon cable connectors completely in one stroke, the older discrete-wire alternatives were still often competitive, partly because of the availability of automated equipment to perform the individual terminations of the separate wires at high speed. So ribbon cable's labor-saving advantage was mitigated. In 1973 an engineer at 3M suggested that a pneumatic ribbon cable terminator with a higher production rate than the hand presses then in use might be feasible. Though 3M had no specific requests for such a machine, ribbon cable product managers encouraged the engineer to develop his idea. The result was a pneumatic assembly press into which an operator could place a connector and the end of a cable; he then pushed an activation button, and the press terminated the connector to the cable. 3M lent prototypes to the Digital Equipment Corporation for field testing, and sold the machine in essentially its original form starting in 1975.

This example illustrates the essentials of supplier innovation. The innovator -- 3M -- did not use the machinery commercially in-house, nor was it sold at a significant profit.

Rather, the innovator benefitted by lowering the relative cost to users of applying one of his existing products.

3 PAST RESEARCH

Two previous studies have reported instances of supplier innovation, but neither one empirically documented a pattern in its occurrence or in how it might be related to the benefit from innovation.

Detailed historical descriptions of innovative activities by certain materials suppliers come from Corey (1956). In several cases suppliers labored to develop methods for using their materials to make products that formerly were made from other materials. Corey's accounts are extremely informative of the nature of supplier involvement in process innovation. They are not intended, however, to comprise a random sample of innovations for statistical analysis.

In a survey of inventions in the U.S. aluminum industry during 1946-57, Merton Peck recorded the development of "new processes in manufacturing products from aluminum" by "producers of aluminum ingot" (Peck 1962). From a sample of 79 inventions for the working of aluminum into finished products he attributes eight (10.1%) to aluminum producers. The figure of 79 includes all inventions in the operations of "joining" (52) and "finishing" (27). These, it appears from the paper, were operations not performed by aluminum producers themselves, but by

their customers. Of these 79, seven are attributed to "primary aluminum producers," and one to "secondary aluminum producers." The analysis includes no empirical data on benefit nor any tests of its influence. In addition, the author claims to have used trade journals as his source of information for selecting inventions and determining their sources. This suggests the possibility of a bias in the sample toward attributing innovations to firms that had innovation-related products to sell and the motivation to contact a journal. And indeed a partial replication of the study by von Hippel confirms the existence of such a bias (von Hippel 1981).

4 STUDY DESIGN

4.1 Industry Selection

Since the goal of the study is to show the existence of supplier innovation and investigate its nature, the researcher sought an industry in which it was likely to be present. Theoretical characteristics of such an industry are suggested by von Hippel (1979, pp. 34-7):

- (1) a large number of process users, no one of which accounts for a large fraction of total supply item use.
- (2) a high rate of consumption in the users' production process of supply items that carry a relatively high profit margin for the suppliers that sell them.
- (3) total sales of supply items that greatly exceed sales of the companion application equipment.

Under these conditions supplier benefit from innovation relative to that of other parties should be especially high. The profit value and high volume of the parts consumed in the production process gives suppliers strong economic incentive to influence how the process is performed. Compared to this potential profit, any one user can realize only small cost savings from innovation (Remember, each user is a small part of the total market). And the equipment manufacturers have much smaller markets to compete for.

Though any number of industries may appear a priori to meet most of these specifications, very few promise to meet them all. In particular, most high-volume production processes that have many small users (e.g., beverage bottling, clothing manufacture, wire forming) use inputs with slim profit margins for their sellers (e.g., bottles, buttons and zippers, structural wire). Knowledge of the electronics industry suggested that electronic wire preparation might meet all the desired criteria, so it was chosen for study, though the researcher initially had no knowledge of its major innovations or their origins.

Wire and cable termination is traditionally a necessary part of the manufacture of almost every common type of electronic equipment. The wires and cables are used primarily to interconnect subassemblies within a piece of electronic equipment, connect the circuitry of the subassemblies to the controls on the cabinet, or link one piece of equipment to another. Preparing the wire/cable involves cutting it to length, stripping insulation off the ends (except when insulation displacement or insulation piercing techniques are used), and

attaching terminals or connectors to the ends. Terminals and connectors are the metal parts actually plugged, screwed, or clipped to the points to which the wires are meant to connect. A terminal attaches to the end of a single wire; a connector attaches to the ends of several.

Table 1 gives some sales and purchase statistics for the industry. The primary headings are the major types of supply items in the industry. Listed for each supply item are estimated 1981 sales and the fraction of the total purchased by its largest user. Below each item are the major categories of equipment used for its preparation/application, and an upper bound estimate of the 1981 sales of this equipment. For an explanation of the criteria used to select the supply item and equipment categories, see section 4.2.

The users of wire termination are highly diffuse. For only one of the major types of wire, cable, terminal, or connector for which data are available does any one firm buy over 5% of total sales, as seen in Table 1. Indeed, electronics is a part of so many products that there are probably thousands of U.S. firms that do some wire preparation. Common users include manufacturers of computers, automobiles, appliances, and aerospace equipment. There are even firms that do nothing but wire preparation, working on a contract basis for the electronic products manufacturers.

The markets for the major types of wire, cable, and termination parts runs into the tens and hundreds of millions of dollars per year, also shown in the table. The bulk of each of these items is supplied primarily by a handful of firms, many of

WIRE AND CABLE	Current Annual Sales (\$mil.)	Largest Single User Consumption Share	Maximum Annual Equip. Sales (\$mil.)
Discrete Hookup Wire	195	<5%	
Cutting and stripping			10
Critical Applications Discrete Wire/a	100	10%	
Nickless stripping			6
Multiple Discrete Wire Cables	250	<5%	
Discrete wire stripping			NA
Ribbon Cable	35	<5%	
Cutting and stripping			1.4
Flat Conductor Cable	75	<3%	
TERMINATION PARTS			
Crimp Terminals	200/b	<5%	
Crimp termination			12
Crimp Connectors	484/c	<5%	
Discrete wire crimping			5
Crimp connector assembly			0.2
Heat-shrink Solder Tubing	NA	NA	
Solder connector assembly			NA
Insulation Displacement Connectors	141	5%	
ID connector assembly			NA
Ribbon Cable Connectors	140	<5%	
Termination			2.5
Flat Conductor Cable Connectors	75	<3%	
Termination			2

TABLE 1: SIZES OF MARKETS FOR WIRE TERMINATION PARTS AND EQUIPMENT

Source : Estimates of marketing and product managers. Discrepant estimates were averaged.

- /a Includes discrete hookup wire and multiple discrete wire cables used primarily in the aircraft and aerospace industries.
- /b Includes crimp contacts for insertion into connector housings. These are applied with equipment classified under "Discrete wire crimping" and inserted with equipment classified under "Crimp connector assembly."
- /c Does not include military-grade connectors.

which do a little wire preparation for their customers, and several of which sell or lease some application equipment for their products.

Termination parts carry high profit margins, as bulk supply items go. According to interviewees within termination parts firms, some larger companies regularly realize a pre-tax return on sales of 20% or more, as compared with a more normal 7% for wire and cable claimed by wire firm personnel.

The annual dollar sales of the application equipment for these supply items are generally much lower than the sales of the items themselves. A glance at the table shows that known equipment sales are never even a tenth the sales of the corresponding supply item. Such pairwise comparisons are misleading because much of the equipment classified under one supply item can be used to handle others, too, but they do serve to demonstrate the large difference in market sizes.

4.2 Classification of Firms

Complications in classifying firms proved minor. None of the firms coded as user regularly sold wire, cable, or termination parts, or any wire preparation equipment. None of the firms coded equipment manufacturer regularly sold any of the supply items or prepared wire or cable for resale. Categorization was less clear-cut for the firms considered within the industry to be suppliers; some perform wire and cable preparation in-house (like a user), and many sell or lease equipment (like a manufacturer). However, their primary benefit from innovating in equipment clearly came from an increased sale

of parts: in-house preparation was purportedly always a minor activity (measured in dollars) compared to part sales, and equipment sales were a break-even activity to support the marketing of parts. It was thus felt correct to call these firms suppliers, as do actual industry participants.

4.3 Sample Selection

The researcher sought a complete sample of the economically "important" equipment innovations of the industry. The process was begun by simply asking users within the industry which improvements in equipment they considered major. The pattern that emerged was that an "important" innovation has wide applicability and offers users large labor productivity increases. Every piece of innovative equipment they identified was applicable to a major class of wire or cable (not merely a subtype thereof) and had a labor productivity at least $1 \frac{2}{3}$ times that of any equipment to do the same job that was previously available. It was therefore decided to use the following selection procedure:

- (1) Identify the five commercially most important types of electronics wire and cable, as measured by sales. (Coaxial cable, often used in electronics, was considered a supply item for the communications industry and therefore omitted at the outset.)
- (2) For each type of wire/cable, identify the steps of preparation that have experienced major equipment innovations, where a "major equipment innovation" is the introduction into commercial production operations of

equipment with a sustainable labor productivity at least $1 \frac{2}{3}$ times that of previously available methods. (For the methods and data used to calculate this "productivity ratio" for each innovation, see Appendix A.)

- (3) For each of the selected process steps find all equipment innovations that meet the criterion for being "major."

The choice of a $1 \frac{2}{3}$ multiplication of labor productivity as a cutoff was somewhat arbitrary. As noted above, $1 \frac{2}{3}$ was the lowest incremental productivity gain of any of the innovations identified as important in the initial round of interviews. When it was adopted tentatively as an acceptance criterion, it was found that it yielded an adequate but manageable number of sample innovations, so it was retained. Focusing exclusively on labor productivity admittedly leaves out other considerations of user utility from technological change. Multi-factor productivity measures can take into consideration the costs of the equipment itself and of the energy and materials consumed in the production process. Measurement was limited to labor requirements because of data availability. How much the innovation list might have changed had acceptance been based on the increase in multi-factor productivity is uncertain.

In practice the researcher performed the steps of the sample selection procedure by extensive telephone interviewing. The list of wire and cable types was verified with marketing managers of major U.S. wire and cable firms. Production personnel in user firms were questioned to find the process steps experiencing major innovation. To identify all the major innovations of each process step, users, manufacturers, and suppliers were all

solicited for histories of equipment development and data on production rates. From this was derived the list of qualifying innovations for each step, which the researcher read back to the interviewees for additions and amendments.

The results are summarized in Table 2. Under the 5 wire types are the applicable process steps, and under each of these are the innovations. Heading the innovation list for each process step is the original method used to perform the step. These "original practice" methods were not counted among the innovations. After each qualifying innovation is also listed the ratio of its production rate per operator to that of the next best equipment available at the time of the innovation's first commercial use, as calculated using the methods of Appendix A.

Many process operations can be performed on the same types of equipment for more than one type of wire or cable. These are included under only one type, with the result that some wire/cable headings do not bear all of their relevant process steps.

4.4 Determination of Innovation Sources

To determine the source of each innovation the researcher first canvassed industry people to find the firm that first introduced it commercially. In the identified firm the development engineers and (where possible) the product managers responsible for the innovative equipment were interviewed to obtain first-hand accounts of the project, except in a few cases. In the exceptional cases it was only possible to have another member of the firm ask the questions of these people and report

Productivity Ratio

DISCRETE HOOKUP WIRE

Cutting and Stripping

Hand tools

- (1) Automatic cut and strip machine NA
- (2) Linear feed cut and strip machine 1.8

Crimp Termination

Dikes

- (3) Automatic lead-making machine 15.1
- (4) Power crimp bench press 2.0
- (5) Strip-fed crimp press 2.0

CRITICAL APPLICATIONS DISCRETE WIRE

Nickless Stripping

Calibrated mechanical strippers

- (6) Thermal stripper >2
- (7) Die-type hand stripper 2.1
- (8) Semi-automatic die-type stripper 1.9

MULTIPLE DISCRETE WIRE CABLES AND ASSEMBLIES/a

Discrete Wire Stripping

Hand tools

- (9) Rotary stripper NA

Solder Connector Assembly/b

Hand

- (10) Heat-shrink sleeve assembly racks 6.3

Discrete Wire Crimping

Hand tools

- (11) Stripper-crimper 2.4

Crimp Connector Assembly

Hand

- (12) Crimp connector assembly machine 2.2

Insulation Displacement Connector Assembly

Hand tool

- (13) Semi-automatic insulation displacement terminator 4.5
- (14) Automatic insulation displacement harness maker 2.1

RIBBON CABLE

Cutting and Stripping

Hand tools

- (15) Automatic ribbon cable cutter 36.5
- (16) Automatic ribbon cable cut and strip machine 63.2

Termination

Hand Press

- (17) Pneumatic ribbon cable press 2.0
- (18) Semi-automatic ribbon cable terminator 4.7
- (19) Automatic ribbon cable harness maker 2.1

FLAT CONDUCTOR CABLE

Termination

Hand welding

- (20) Flat conductor cable crimp stitcher 6.0

TABLE 2: INNOVATION SAMPLE (Footnotes next page)

- /a The category "multiple discrete wire cables and assemblies" includes some discrete hookup wire; specifically, the hookup wire bought by users to construct wiring harnesses. It was included under this category because the process equipment required to prepare it is often the same as that used for multiple discrete wire cables.
- /b There are three generic connector types, each requiring distinct application equipment: solder, crimping (requiring the operations of discrete wire crimping and crimp connector assembly), and insulation displacement. All three were included because industry interviewees claimed they were all in widespread use.

their responses. Any contact during development with outside firms or individuals was noted. These outside parties the researcher then contacted to determine whether any had contributed design ideas to the effort. As a final check on origin the researcher asked disinterested experts on the process operation involved for any evidence that similar equipment existed anywhere else before the commercial introduction. When any of this revealed a development project that preceded the commercializer's, the procedure was begun anew, the earlier project being researched in the same manner.

The date and source of each innovation are listed in Table 3. An inability to collect first-hand information made it impossible to determine with confidence a source for any innovation introduced before 1935, so such innovations were excluded from statistical analysis. The date is the year of first completion of a unit used in commercial production operations. Where the exact date is unknown there is presented as narrow a range of years as could be determined.

5 FINDINGS

5.1 Innovation Sources

As hypothesized, suppliers were a major source of innovations. Omitting the two innovations of undetermined source, 56% are attributed to suppliers and 44% to nonsuppliers.

Of 20 innovations identified, for 10 it was a supplier firm

INNOVATION	SOURCE /a	DATE
Termination Equipment		
(3) Automatic lead-making machine	User-Manufacturer	1939
(4) Pneumatic crimp bench press	Supplier	1942-43
(5) Strip-fed crimp press	Supplier	1946
(10) Heat-shrink sleeve assembly racks	Supplier	1971-73
(11) Stripper-crimper	Supplier	1951-52
(12) Crimp connector assembly machine	Supplier	1977
(13) Semi-automatic ID terminator	Supplier	1972
(14) Automatic ID harness maker	Supplier	1978
(17) Pneumatic RC press	Supplier	1974
(18) Semi-automatic RC terminator	Supplier	1980
(19) Automatic RC harness maker	Manufacturer	1981
(20) Flat cable crimp stitcher	Supplier	1962
Wire- and Cable-Handling Equipment		
(1) Automatic cut and strip machine	NA	pre-1935
(2) Linear feed cut and strip machine	Manufacturer	1956
(6) Thermal stripper	User	1940
(7) Die-type hand stripper	Manufacturer	1965-70
(8) Semi-automatic die-type stripper	User-manufacturer	1979
(9) Rotary stripper	NA	pre-1935
(15) Automatic RC cutter	Manufacturer	1977
(16) Automatic RC cut and strip machine	Manufacturer	1977

TABLE 3: INNOVATION SOURCES AND COMMERCIALIZATION DATES

/a The source of an innovation is the category of the firm that designed and built the first unit of equipment embodying the innovation that was used in commercial production operations. The categorization depends on how the firm benefitted from the innovative equipment, whether by using it (user), selling it (manufacturer), or employing it to promote the sale of the supply item used in it (supplier).

that designed and built the first machine embodying the innovative function to be used in commercial production operations. In none of these cases did the investigation uncover any outside party that contributed significant design ideas or funds to the project. User input, if present at all, was typically limited to indefinite requests for more automated equipment.

Another 8 innovations were nonsupplier: a manufacturer developed the equipment in 5 cases, a user in 1 case, and 2 innovations were the result of joint user-manufacturer development projects. The 2 remaining innovations were too old (pre-1935) for reliable determination of a source, so they were omitted from statistical analysis.

Examining the differences between the innovations from suppliers and those from nonsuppliers revealed an interesting pattern. This pattern is apparent when the innovations are divided according to type of supply item handled: equipment that processes only wire or cable and equipment that applies termination parts. As seen in Table 2, suppliers originated 10 innovations for handling termination parts, but none strictly for wire and cable handling. Nonsuppliers, in contrast, originated 2 for termination and 6 for conductors. Looked at differently, 10 of the 12 termination innovations were the work of suppliers, while none of the strictly conductor-handling innovations were -- nonsuppliers accounted for all 6 of those.

This is a stronger pattern than one would expect from chance alone. Using a Fisher Exact test, one can test the hypothesis that suppliers were just as likely to have introduced one of the

purely wire/cable innovations as they were one of the innovations that handles termination parts. The result is a rejection of the hypothesis at the .005 level of statistical significance. (Specifically, the sample consists of 12 innovations of the termination type and 6 of the wire/cable type, and 10 of the total 18 are of the supplier source. Now consider the hypothesis that the probability of an innovation being of the supplier source is independent of the innovation's type. Given the above-mentioned data conditions, under the null hypothesis the probability that as many as 10 of the supplier-source innovations are of the termination type is .00151.)

5.2 Test of Source-Benefit Correlation

The researcher undertook to test the relationship between relative benefit and the sources of the innovations in the sample on a case-by-case basis. Data were solicited to enable estimates of potential benefit for each of the 18 pieces of innovative equipment, and for 9 of them the attempt was successful. For each of the 9, three calculations were made:

- (1) Supplier benefit: the total profit on all parts used in all active units of the innovative equipment in the year 5 years after its commercial release.
- (1) Manufacturer benefit: the potential profit on all units placed with users during the fifth year after commercial release.
- (3) User benefit: the cost savings from the equipment to the single largest user during the fifth year after commercial release.

Focus on the fifth year was somewhat arbitrary: there were insufficient data to perform complete time discounting of profit streams, and so this was chosen as a representative period. For the exact methods of calculation and consideration of some of the simplifying assumptions, see Appendix B. Many of the data are proprietary, revealed on condition of confidentiality. They are therefore not reproduced here.

Unfortunately, what is here called "supplier benefit" is a gross overstatement. The interviewees in supplier firms explained that much or most of the parts put through their innovative equipment they would have sold whether they had originated the equipment or not. Many customers that already used or planned to use an innovating supplier's part would be among those acquiring the machine. So to estimate true supplier benefit from an innovation we would need an estimate of the fraction of the total part consumption that was "new business."

Again unfortunately, no one felt qualified to estimate such a number. The new business fraction is highly uncertain, even in retrospect. To predict what it will be (in the case of innovations released less than 5 years ago) or would have been had a supplier been the innovator (in the case of innovations originated by manufacturers or users) is high guesswork.

Nonetheless, to make it possible to perform a test the theory was modified: suppliers will tend to be the source of innovations for which the "supplier benefit", as defined above, is very high relative to the benefit of nonsuppliers. For each of the 9 innovations the researcher calculated the ratio of "supplier benefit" to the benefit of the actual innovator (in the

case of a nonsupplier innovation), or to the benefit of the nonsupplier party with the highest benefit, which was considered the logical alternative innovator (in the case of a supplier innovation). The results were then rank ordered as shown in Table 4.

Informal inspection of the rank order list reveals no strong relationship between the size of the potential benefit of suppliers relative to nonsuppliers and the source of an innovation. Manufacturer and user innovations are near the top and bottom of the list while supplier innovations dominate the middle. To test rigorously, one can use the Mann-Whitney U procedure to test the null hypothesis that the distribution of benefit ratios is the same for supplier and nonsupplier innovations against the alternative hypothesis that the benefit ratios for supplier innovations come from a higher distribution than the distribution for nonsupplier innovation ratios. The result is that the test cannot reject the null hypothesis at even the 50% level of statistical significance. (More precisely, $U=10$ for the nonsupplier group, and the probability of a U-value that small or smaller under the null hypothesis is .548.) So it was not possible to offer evidence that supplier innovation tends to occur more frequently among innovations with a high relative supplier benefit.

Conversely, the analysis has not offered strong proof against the hypothesis. The measures of benefit utilized many simplifying assumptions that may have severely reduced their accuracy (See Appendix B). Furthermore, the sample was so small that the chance of accepting the no-relationship hypothesis even

<u>Rank</u>	<u>Source</u>	<u>Innovation Type</u>	<u>Highest Nonsupplier Benefitter</u>	<u>Ratio Taken</u>	<u>Benefit Ratio</u>
1	Manufacturer	Wire/Cable	Manufacturer	Sup/Man	543.2
2	Supplier	Termination	Manufacturer	Sup/Man	268.6
3	Manufacturer	Termination	Manufacturer	Sup/Man	257.2
4	Supplier	Termination	User	Sup/Use	187.4
5	Supplier	Termination	User	Sup/Use	43.2
6	Supplier	Termination	Manufacturer	Sup/Man	4.2
7	Manufacturer	Wire/Cable	Manufacturer	Sup/Man	3.0
8	Supplier	Termination	Manufacturer	Sup/Man	1.2
9	User-Manu.	Termination	User	Sup/Use	0.2

TABLE 4: RANKING OF INNOVATIONS ACCORDING TO RATIO OF SUPPLIER
BENEFIT TO NONSUPPLIER BENEFIT

if it were false (i.e., the probability of a type II error) was probably very high.

6 ADDITIONAL EXPLANATORY FACTORS

When they were questioned directly the interviewees had several explanations for the pattern of innovation sources found. In particular, they forwarded reasons for why termination parts suppliers might be expected to innovate in application equipment where wire and cable suppliers did not. It was not possible to quantify these hypotheses, but they are outlined here for consideration. But first as an introduction there is a summary of these people's observations on the motivations for supplier innovation in general.

6.1 Supplier Innovation Strategy

Industry interviewees gave detailed explanations for why the suppliers in the sample innovated. Suppliers gained nothing from the sale of the equipment itself: all claimed to try to price their equipment just to break even on it. Sometimes they even took a loss. They benefitted by using the innovative equipment to increase sales of their parts, though the mechanisms through which this occurred varied.

When a firm is the dominant supplier of a particular item, as 3M was in ribbon cable and ribbon cable connectors during the early 1970s, it can benefit from the free dissemination of any equipment to lower application cost. The supply item becomes

cheaper for users to incorporate into their products, so some switch to it from the functional alternatives. Chances are that the bulk of this sales increase will fall to the dominant supplier, whence comes his motivation to innovate.

The situation is more complex when the supplier has only a minor share of the market for a supply item. Under these circumstances it doesn't help as much to increase the entire market for the item. It can be easier to gain sales by luring customers directly from the competing brands, appropriating market share. In practice suppliers accomplish this by leasing their innovative application equipment and making the use of their brand of part a condition of the lease. In some cases such leasing arrangements will consist simply of a minimum required monthly or annual purchase of parts per machine. There are also some legal sanctions available to suppliers. In Japan and Europe a supplier can sometimes require outright that users employ only his parts in equipment he has leased to them. In the U.S. this is not possible, but a supplier can charge a "usage fee" on equipment and make it applicable only when competitors' parts are used in the machine. This makes the use of competitive parts economically unattractive. And lastly, as legal owner of the equipment the supplier retains responsibility for repair. If users put foreign parts through the machinery the suppliers' repair staff can threaten to refuse to service it on the grounds that it has not been treated in accordance with recommendations. For some or all of these reasons users that want to use a particular supplier's equipment will be influenced to buy his parts for use in it also. When these users are firms that

otherwise would have bought competing brands the supplier scores an increase in sales.

6.2 Differences Between Wire and Terminal Firms

Some of the respondents argued that wire suppliers simply do not have the expertise to design and manufacture process machinery. This argument rests on the point that wire suppliers are expert in metal drawing, plastics extrusion, and various other operations that prepare them but poorly for mechanical equipment innovation.

This argument is questionable for a couple of reasons. First, wire manufacturing firms do have some experience with the process equipment. Some of the largest claimed that they do wire and cable preparation in-house on a contract basis, and modify the process equipment to suit their needs. And in at least two cases of cable-handling innovation by manufacturers, the major suppliers of the cable also sold termination parts for which they had originated application tooling innovations in the sample. So there clearly existed suppliers with machinery expertise that failed to innovate in the equipment to handle their cable. Second, the termination part suppliers allegedly did not all have significant equipment expertise originally either, and yet they innovated. They acquired the necessary skills somehow.

6.3 Greater Standardization of Wire and Cable

Some maintained that if a supply item is highly standardized a supplier has no incentive to introduce application equipment for it. Any firm's brand of item could be used in the equipment,

so introducing the machine would not much benefit any one supplier. In effect, a supplier's economic benefit from equipment innovation is much lower if the item handled is undifferentiated. Since the types of wire and cable used in the high-volume equipment listed here are highly standardized, our calculated benefit might have been overly large for wire and cable innovations.

It may well be that the more standardized a supply item the more difficult it is for a supplier to link use of his part to use of his equipment. However, it is difficult to accept that standardization rules out supplier innovation completely, for there exist counterexamples. There were at least two cases of supplier innovation in which the machinery would accept competing brands of the supply item directly, and at least one more where it could do so with minor adjustment. The innovator firms in these cases insured that users would put their brand of part in the equipment by leasing the equipment and imposing the sorts of leasing controls mentioned previously.

6.4 Different Expectations

Some industry participants argued that suppliers of wire, unlike suppliers of termination parts, "just never got involved" in application equipment production. Initially this response sounds circular (Why did they not get involved?) but there is a logic to it.

For whatever reasons -- greater economic incentive, greater expertise, greater differentiation of product -- termination part

suppliers apparently undertook regular development of automated application tooling before equipment manufacturers, whereas wire suppliers did not. Thus, in termination "everyone knows" that if a supplier leapfrogs competitors in application tooling he can pirate away significant sales from them, and if he lags in this department his sales will gradually erode as users switch to the firms with the best equipment. Users themselves have little incentive to develop new equipment since the suppliers are doing the work for them. Manufacturers may occasionally introduce some equipment for termination (as they in fact have), but are discouraged by the saturation of demand by suppliers, many of whom sell or lease equipment at no profit. In contrast, in wire and cable handling "everyone knows" that whatever equipment a supplier could produce some manufacturer will also produce and may already be working on. And the manufacturers' versions will handle all brands of supply items. It is thus pointless for a supplier to try to innovate. The benefit calculations, according to this line of reasoning, are incorrect because they omit these strategic factors.

This argument, too, has weaknesses. It seems to say that firms will never try to break into new markets. Certainly the two termination innovations introduced by nonsuppliers could be considered contradictory evidence. Unfortunately, it is impossible even to begin to test the hypothesis here: that would require twenty industries, not twenty innovations.

7 CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

This study has probably raised more questions than it has answered. It has established the existence of supplier innovation and discovered some components of its motivation and nature. Precisely why supplier innovation occurs when and where it does remains something of a mystery, however. But perhaps it is a mystery not because we do not have the answer, but because we cannot test the answer to be certain. Economic incentive theories, which have achieved some success in other studies (Spierings 1979, von Hippel 1979) looked throughout the sample selection as though they could explain most of the innovation source variation. Unfortunately the market and strategic considerations that shape potential innovators' expectations of benefit in the industry were so many and complex that it proved too difficult to gather the data necessary for a realistic test. If nothing else, it is hoped that this study has at least pointed the way to a fruitful area of inquiry.

To probe this research question further, it would be desirable to have more detailed historical data for each innovation and to survey a set of industries, rather than merely the innovations within a single industry. Lack of detailed data made it difficult to give even the simplest hypotheses a fair test. Gathering information for a set of industries might reveal or help to verify industry-specific factors that influence the degree of supplier involvement in process innovation. The problem with gathering more and better data is, of course, limitations on time and ability. Many of the data of interest

for analysis of individual innovations are proprietary, internal information of a particular firm. It is often very time-consuming to locate anyone who claims to know them accurately, and very difficult to induce these people to reveal them, even with promises of confidentiality. Perhaps some more aggregated and readily accessible variables could be used in a cross-industry study.

APPENDIX A: COMPUTATION OF PRODUCTIVITY RATIO OF INNOVATIVE EQUIPMENT

The criterion for inclusion of an innovation in the sample was that its sustained labor productivity be at least $1 \frac{2}{3}$ times that of the next best equipment available at the time of first commercial use of the innovative equipment. "Next best equipment" here refers to the piece or combination of pieces of equipment that had the next highest labor productivity. To test candidate innovations the researcher calculated a "productivity ratio" and compared it to $1 \frac{2}{3}$. This is the ratio that appears after each innovation in Table 2.

The formula for this ratio depended on whether the innovative equipment was compared to 1 or 2 pieces of alternative equipment. If the new equipment executed an operation that was formerly done on one piece of equipment the formula was:

$$\text{PRODRAT} = (\text{FIO} \times \text{PI} / \text{OI}) / (\text{FAO} \times \text{PA} / \text{OA})$$

where FIO = the fraction of the total paid operator time that the innovative equipment is in actual operation -- excludes repair and set-up time. (Fraction)

PI = the production rate of the innovative equipment while it is in actual operation. (Completed wires, cables, or terminations/machine-hour)

OI = the number of operators required per unit of the innovative equipment. (Operators/machine)

FAO = the fraction of the total paid operator time that the alternative equipment is in actual operation -- excludes repair and set-up time. (Fraction)

PA = the production rate of the alternative equipment while it is in actual operation. (Completed wires, cables, or terminations/machine-hour)

OA = the number of operators required per unit of the alternative equipment. (Operators/machine)

In several cases the innovative equipment combined operations formerly performed on two separate pieces of equipment. In such cases a modified version of the formula was used:

$$\text{PRODRAT} = (\text{FIO} \times \text{PI} / \text{OI}) / [1 / (1/\text{POA1} + 1/\text{POA2})]$$

where POA1 = FAO $\times$ PA/OA, as defined above, for the first piece of alternative equipment, i.e., the sustained hourly output per full-time operator. (Wires, cables, or terminations/operator-hour)

POA2 = FAO $\times$ PA/OA for the second piece of alternative equipment. (Wires, cables, or terminations/operator-hour)

When interviewees said that operator time lost to repair and set-up time was negligible, the operation fraction (FIO or FAO) was set equal to one.

When the production rates of the equipments under consideration depended on the form of the output (length of wire, configuration of terminations, etc.) interviewees were asked for a "typical" form and the rates applicable to that were used.

The productivity data collected for each innovation are given in Table 5.

INNOVATION ALTERNATIVE EQUIPMENT		FIO	PI	OI	FAO	PA	OA
(2)	Linear Feed C & S Machine/a Automatic C & S Machine	0.97	7000	0.25	0.75	3400	0.16
(3)	Automatic Lead-Making Machine/b Automatic C & S Machine Crimper Dikes	0.75	3000	1	0.75 1	3400 150	0.17 1
(4)	Pneumatic Crimp Bench Press/c Crimper Dikes	1	150	1	1	75	1
(5)	Strip-Fed Bench Press Power Crimp Bench Press	1	600	1	1	300	1
(6)	Thermal Stripper Calibrated Mechanical Strippers	1	400	1	<1	<200	1
(7)	Die-Type Hand Stripper Thermal Stripper	1	845	1	1	400	1
(8)	Semi-Automatic Die-Type Stripper Die-Type Hand Stripper	1	1579	1	1	845	1
(10)	Heat-Shrink Sleeve Fixtures Hand Assembly	1	545	1	1	86	1
(11)	Stripper-Crimper/d Rotary Stripper Strip-Fed Bench Press	1	900	1	1 1	540 1200	1 1
(12)	Connector Assembly Machine Strip-Fed Bench Press Hand Crimp Insertion	1	1000	1	1 1	1200 720	1 1
(13)	Semi-Automatic ID Terminator ID Hand Tool	1	1250	1	1	275	1
(14)	Automatic ID Harness Maker/e Linear Feed C & S Machine Semi-Automatic ID Terminator	1	2500	1	0.97 1	7000 1250	0.25 1
(15)	Automatic Ribbon Cable Cutter/f Pneumatic Ribbon Cable Press/g	1	3500	1	1	96	1
(16)	Automatic RC C & S Machine/h Automatic Ribbon Cable Cutter Abrasive RC Stripper	1	2500	1	1 1	3500 40	1 1

TABLE 5: LABOR PRODUCTIVITY DATA FOR INNOVATIONS SAMPLED
(continued on next page)

(17) Pneumatic Ribbon Cable Press/i Hand Ribbon Cable Press	1	96	1	1	48	1
(18) Semi-Automatic RC Terminator Pneumatic Ribbon Cable Press	1	450	1	1	96	1
(19) Automatic RC Harness Maker/j Automatic Ribbon Cable Cutter Semi-Automatic RC Terminator	1	450	1	1	3500	1
				1	225	1
(20) Flat Conductor Cable Stitcher Hand Soldering	1	3600	1	1	600	1

TABLE 5: LABOR PRODUCTIVITY DATA FOR INNOVATIONS SAMPLED (continued)

- /a Assumes machines are cutting 8-inch wires.
- /b Assumes machines are cutting 8-inch wires with a terminal attached to one end.
- /c Assumes tools are applying heavy-duty terminals of the sort used in WWII aircraft.
- /d By the time of release of the stripper-crimper the production rate of the strip-fed bench press had improved to nearly 1200 crimps/hour.
- /e Assumes terminations of 8-inch wires.
- /f Assumes machines are cutting 24-inch cables.
- /g The pneumatic ribbon cable press is used for cutting as well as terminating.
- /h Assumes machines are cutting 24-inch cables and stripping them at one end.
- /i Termination rates for ribbon cable are given in numbers of connectors attached per hour, not the number of individual wires terminated per hour. Attaching one ribbon cable connector is the equivalent of terminating as many as 50 individual wires.
- /j Assumes machines are cutting 24-inch cables and attaching a connector to each end.

APPENDIX B: CALCULATIONS OF ECONOMIC BENEFIT

To calculate the economic benefit to each party from an equipment innovation a set of standard formulas was established.

The formula for supplier benefit was:

$$\text{SUPBEN} = \text{TP} \times \text{PC} \times \text{PP} \times \text{UF} \times \text{SRS} \times 2112$$

where TP = total accumulated placements (sale or lease) of equipment during the first five years after commercial release. I.e., the "number of machines in the field."
(Machines)

PC = the hourly part consumption of a unit of equipment in operation. (Parts/machine-hour)

PP = the average price of the parts used in the equipment.
(Dollars/part)

UF = the fraction of the working day that the average piece of equipment is actually in use. (Fraction)

SRS = the supplier's return on sales from the sale of the parts. (Fraction)

2112 = the normal number of work hours in a year for user wire preparation operations. (Hours/year)

The formula for manufacturer benefit was:

$$\text{MANBEN} = \text{MP} \times \text{PE} \times \text{MRS}$$

where MP = the number of units of equipment placed during the fifth year after commercial release. (Machines/year)

PE = the average sales price for one unit of equipment.
(Dollars/machine)

MRS = the manufacturer's return on sales from sales of the equipment. (Fraction)

The formula for user benefit was:

$$\text{USEBEN} = [(\text{LA} \times \text{PI} \times \text{FO}) / (\text{FA} \times \text{PA} / \text{OA}) - (\text{FI} \times \text{OI} \times \text{LA})] \times 21120$$

where LA = the largest accumulation of equipment by any one user firm in the first five years after commercial release.
(Machines)

PI = the production rate of the innovative equipment while it is in actual operation. (Completed wires, cables, or terminations/machine-hour)

FO = the fraction of work time that the innovative equipment is in actual operation -- excludes idle, repair, and set-up time. (Fraction)

FA = the fraction of the total paid operator time that the next best alternative equipment is in actual operation -- excludes repair and set-up time. (Fraction)

PA = production rate of the next best alternative equipment while it is in actual operation. (Completed wires, cables, or terminations/machine-hour)

OA = number of operators required per unit of the next best alternative equipment. (Operators/machine)

FI = the fraction of work time that the innovative equipment must be tended to by operators -- includes repair and set-up time. (Fraction)

OI = number of operators required per unit of the innovative equipment. (Operators/machine)

21120 = the typical annual wages and overhead for equipment

operators. (Dollars/operator)

For each of the nine innovations, estimates were obtained for all symbolic variables in the equations. For innovations not yet released a full 5 years, the estimates are projections.

When interviewees said that operator time lost to repair and set-up time was negligible, the operation fraction (FAO) was set equal to one. When the production rates of the equipments under consideration depended on the form of the output (length of wire, configuration of terminations, etc.) the interviewees were asked for the most "typical" form, and the rates for that were used.

A number of simplifications in the calculations and data collection may have contributed to inaccuracy in the benefit estimates. Those considered the most serious are discussed below.

Use of current amounts for economic variables. For lack of historical data, the price of parts (PP), the price of a unit of innovative equipment (PE), the wages and overhead for one operator (21120), the supplier's return on sales of parts (SRS), and the manufacturer's return on sales of equipment (MRS) were set equal to their current values. As far as the prices and labor costs are concerned, this simplification is of no consequence for the calculation of relative benefits if all these quantities have risen since the fifth year after commercialization by exactly the same proportion. If not, this has introduced biases. If the return on sales percentages are higher (lower) than in the years just after the commercialization of the equipment, the supplier and manufacturer benefit figures

will be relatively too high (low).

Use of actual results for hypothetical situations. In each case only one of the three parties originated the innovation. The benefit of this party was calculated from actual historical market data (or projections). The benefit for each of the other two parties is, in theory, what they would have gotten had they been the innovators instead. But to estimate this, data from the actual innovator's experience was used, which may be unrealistic. For example, when a supplier originated an innovation, it is implicitly assumed that if a manufacturer had done so instead he would have placed just as many units with users at the same price. In reality, a manufacturer might have placed more (because his machines will use all brands of part) or fewer (because the suppliers' marketing organizations are larger). His price might have been higher (because he takes a bigger markup on equipment) or lower (because his expertise and production efficiency in equipment is greater). Likewise, if a user had originated the equipment he might have incorporated more or fewer units into his operations, been able to design it more or less effectively, etc. Analogous problems arise regardless of who originated the innovation.

Lack of consideration of "new business fraction." As noted in the main text, only some fraction of the parts running through a supplier's innovative equipment are "new business" -- parts the supplier would not have sold but for his offering the equipment to go with them. It is the profit on this portion of the total parts, not the total itself, that is normally considered the innovating supplier's benefit. Inability to get estimates of new

business fractions for the innovations forced use of the procedure of simply calculating the profit on total part consumption and taking ratios of supplier benefit to next-highest benefit. This simplification would not affect the rank ordering of relative benefits if the new business fraction is actually the same for each innovation. But where it differs greatly from innovation to innovation, applying the true fractions might produce a re-ordering of the list.

The actual fraction of machine part consumption that is new business is a difficult number to estimate. It depends in complex ways on the supplier-innovator's market share, the responses of competitors to the new equipment, the substitutability of competitive parts, and more. No simple method of estimating it in particular cases was known, or it would have been used. Nor was there an obvious argument for why the new business fraction might tend to be higher or lower for termination equipment innovations than for wire and cable equipment innovations, or for why it might tend to be higher or lower for the innovations that were originated by suppliers than for the innovations that were originated by nonsuppliers. The analysis is thus currently unable to identify a systematic bias in the hypothesis test resulting from this simplification.

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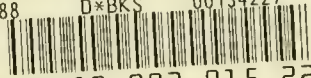
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